

The Mass Loss Rates of O Stars Determined from FUSE Observations

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The Importance of \dot{M}

1. Chemical Evolution of the Galaxy
2. Dynamics of the ISM
3. Deriving Ages and IMFs from HRDs and integrated spectra

Measuring \dot{M}

Three ways (All assume a homogeneous, spherically symmetric wind with a monotonic velocity law).

In a perfect world, they would all agree.

1. Continuum excesses from free-free emission

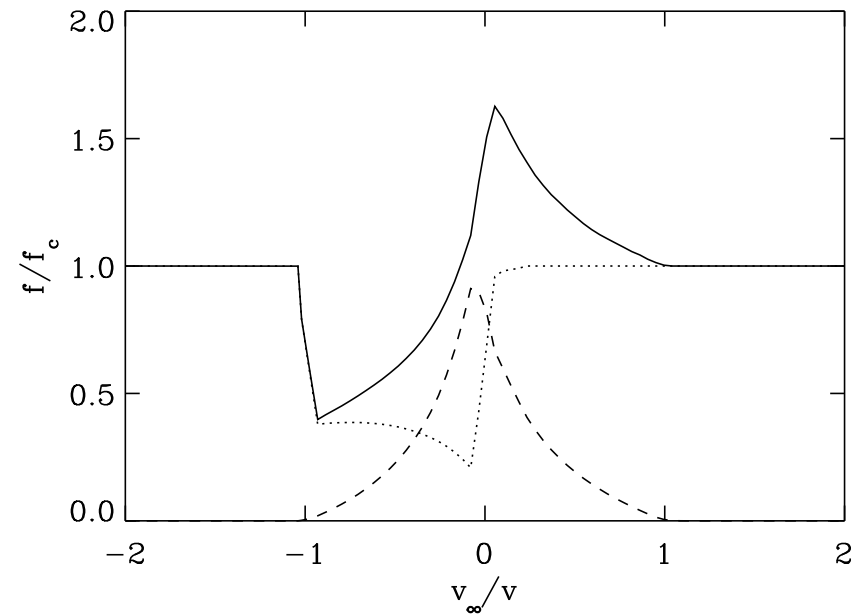
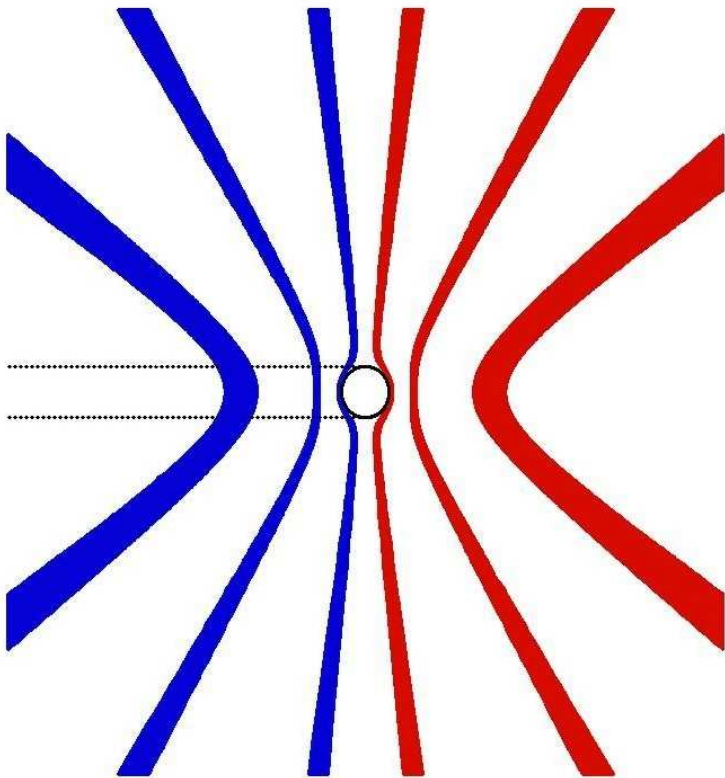
- Samples the outer wind (radius depends on wavelength)
- Depends on n_e^2
- Radio wavelengths are considered the “cleanest” because
 - ▶ Massive winds become thick at large radii ($\gtrsim 10R_*$) where $v = \text{Const}$, making $\rho_{wind} \sim \dot{M}/r^2$, independent of $v(r)$.
 - ▶ No photospheric correction is needed.
- However,
 - ▶ Radio can be non-thermal, requiring fluxes at multiple λ s.
 - ▶ Only detectable for **massive** winds of **nearby** stars.

2. $H\alpha$

- Samples the inner wind.
- Depends on n_e^2
- Easy to observe.
- However, interpreting the $H\alpha$ profile:
 - ▶ Depends on b_3 in the wind, which depends on:
 - the photospheric radiation field
 - the diffuse radiation field of the wind
 - the wind velocity law in the acceleration region
 - ▶ Requires a “photospheric” $H\alpha$ profile.
 - ▶ Furthermore, $W_\lambda(H\alpha)$ can be strongly variable.
- Nevertheless, relatively sophisticated models for $H\alpha$ formation give reasonable agreement between radio and $H\alpha$ \dot{M} s.

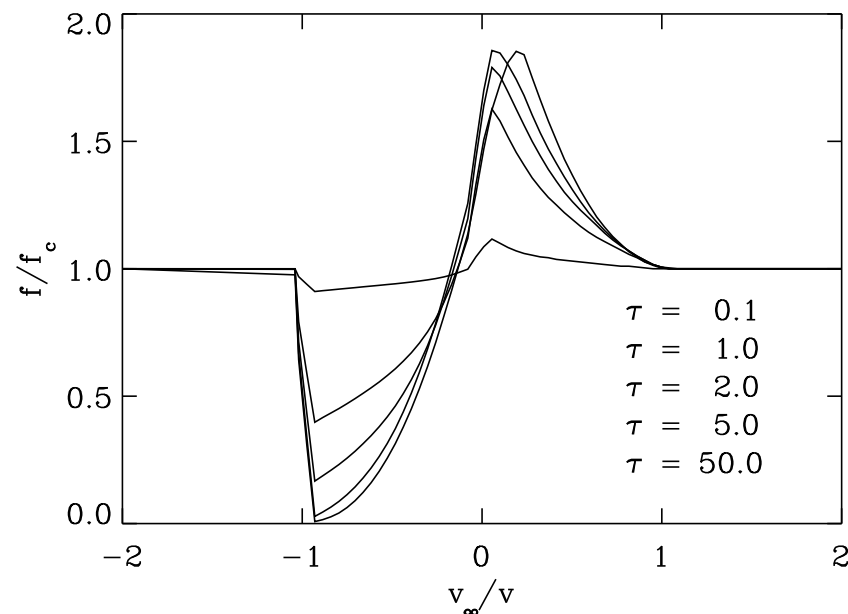
3. UV resonance lines

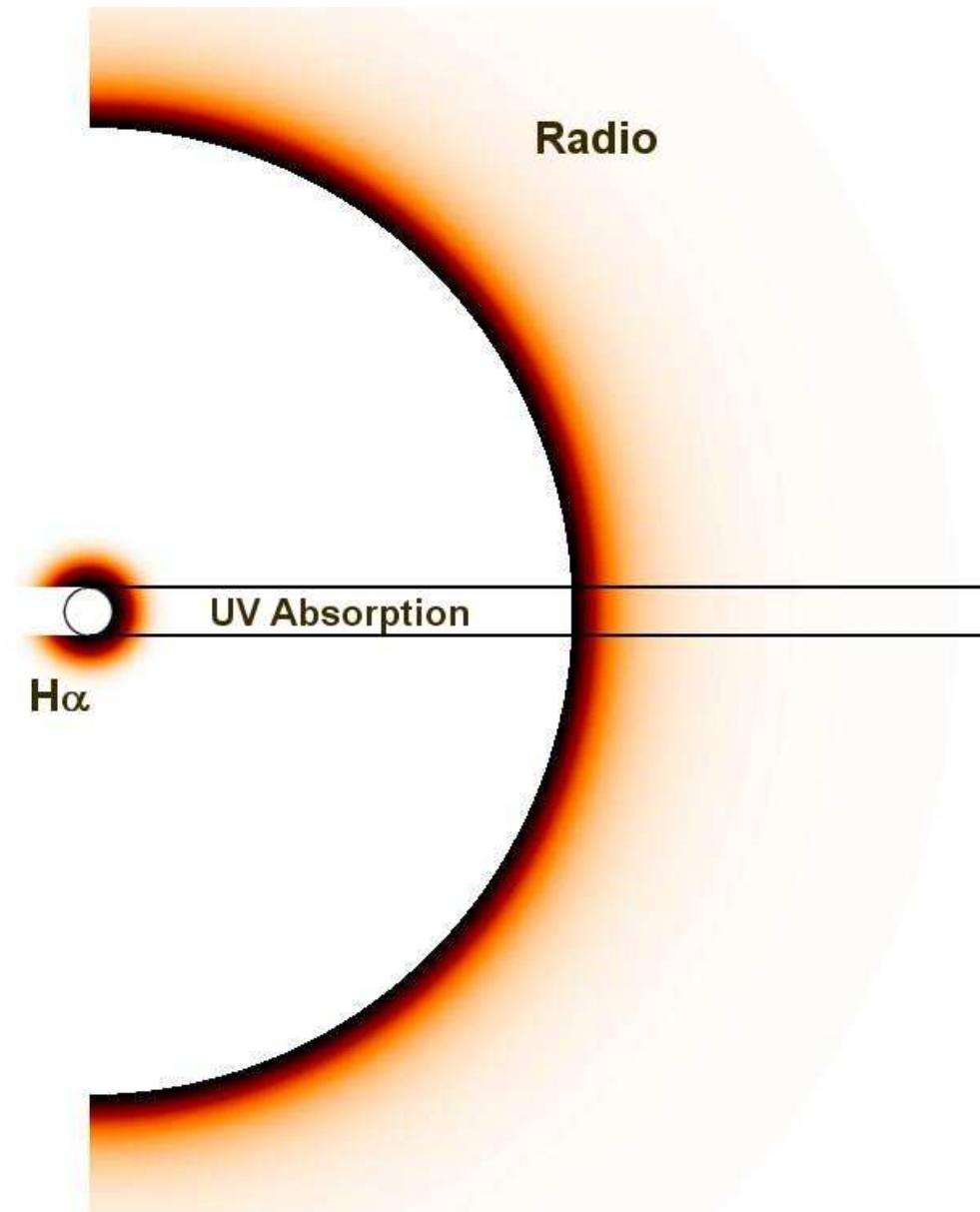
- Samples the entire wind.
- Depends on N_i
- Determines $\tau_{rad} \sim \dot{M} q A_E$



3. UV resonance lines

- Samples the entire wind.
- Depends on N_i
- Determines $\tau_{rad} \sim \dot{M} q A_E$
- However,
 - ▶ Need $\tau_{rad} \leq 5$ for accurate measurements.
 - ▶ Need **dominant ions** ($q \sim 1$) to estimate \dot{M} directly.
 - ▶ But $\tau_{rad} \gg 5$ for dominant ions of abundant elements in the winds detected in the radio or with reliable H α \dot{M} s.

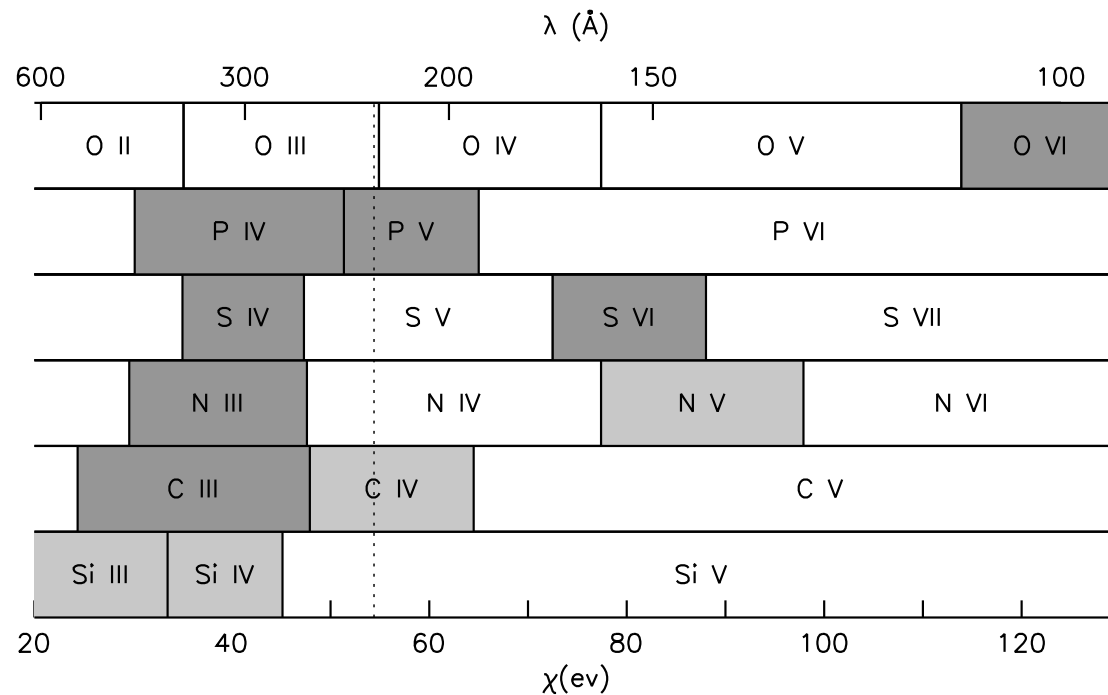




Cartoon showing where the radio free-free emission, $H\alpha$ emission and UV wind line absorption are formed.

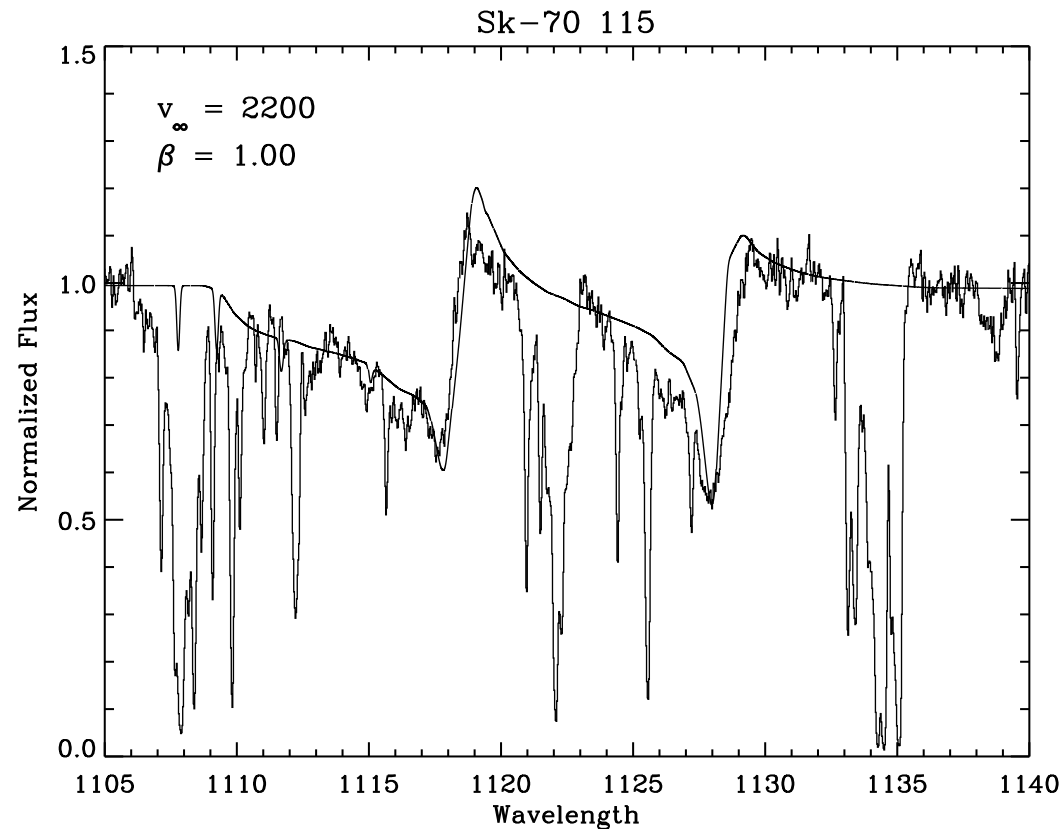
FUSE and P v

- ▶ *FUSE* gives access to P v $\lambda\lambda 1118, 1128$.
- ▶ P v is a surrogate for C IV *and* unaffected by processing.
- ▶ Both expected to have $q \sim 1$ in mid-O star winds.
- ▶ For scaled solar abundances, $\tau_{rad}(\text{C IV})/\tau_{rad}(\text{P v}) = 661$.
- ▶ Detect P v if $\tau_{rad}(\text{C IV}) \gtrsim 50$ – stars with radio detections.

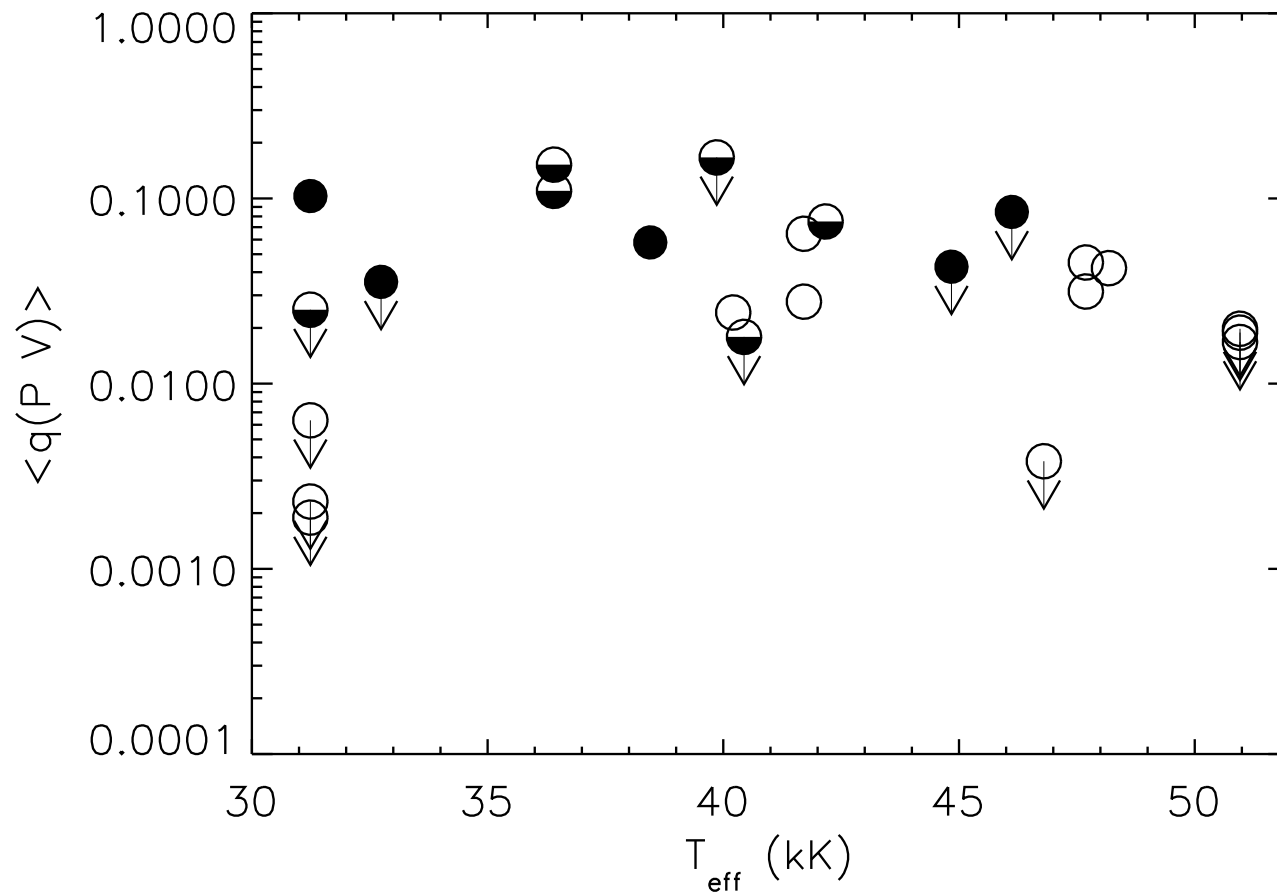


P v in the LMC

- ▶ First large P v study using *FUSE* analyzed 25 LMC O stars (Massa, Fullerton, Sonneborn & Hutchings 2003)
- ▶ v_{∞} and β are determined from other, saturated lines.



- Using predicted \dot{M} s and $A_E(LMC) = 0.6A_E(MW)$, we found:
1. $q(P \ v) \leq 0.15$ for all the stars in the sample.
 2. This result implies a factor of 7 or more discrepancy between expected and observed \dot{M} s.

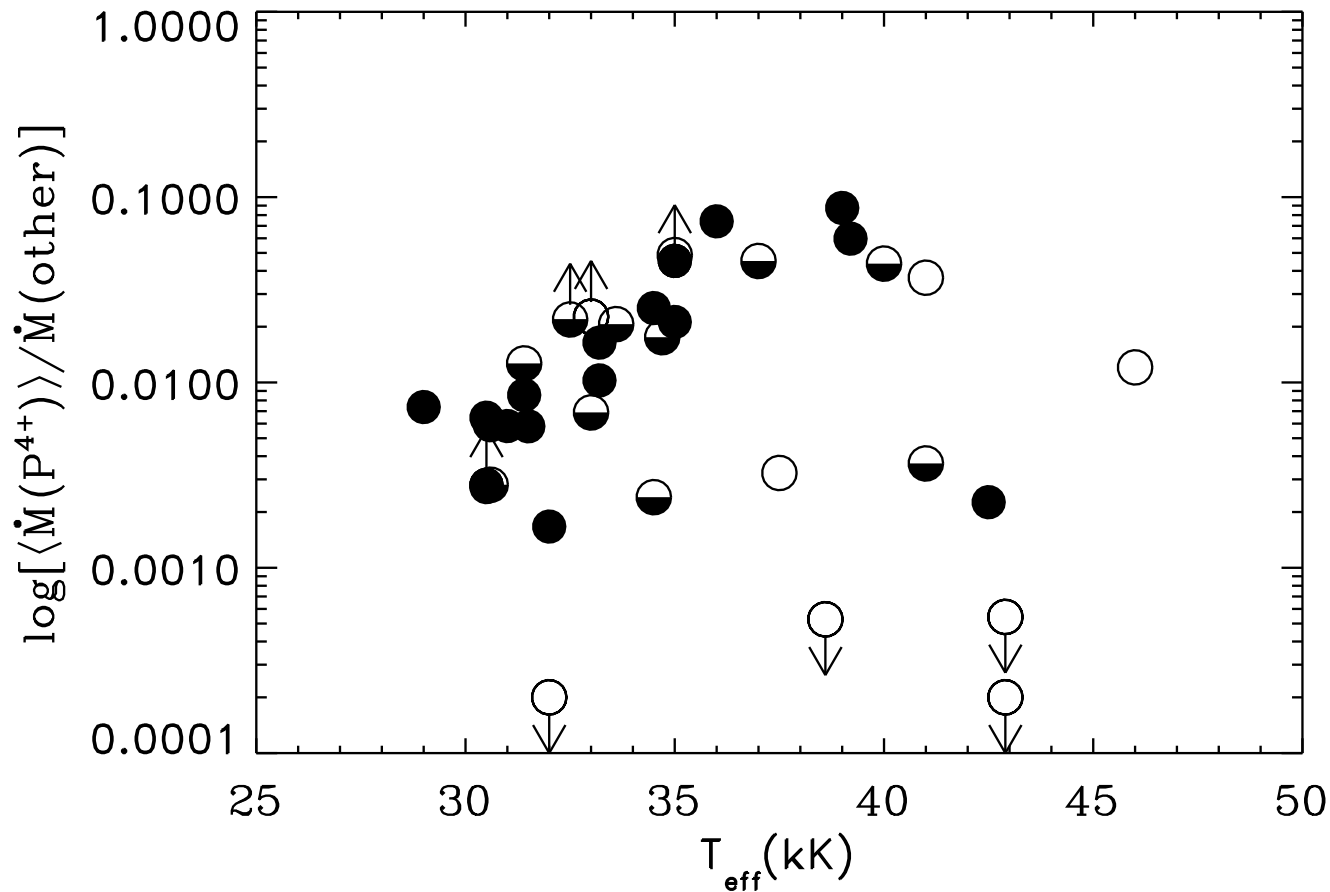


► Three possible explanations:

1. LMC P abundance scales differently from other elements.
2. Theoretical \dot{M} s are incorrect for the LMC.
3. Real winds violate assumptions in SEI model.

P v in the Galaxy

- ▶ Solar, Stellar and ISM P abundances are secure and agree.
- ▶ Fullerton, Massa & Prinja (2006) analyzed P v in *Copernicus*, *Orfeus* and *FUSE* data for 40 stars with radio and/or $\text{H}\alpha$ \dot{M} estimates.



Conclusions

- ▶ MW and LMC results are identical \Rightarrow theory is consistent.
- ▶ P abundance is not responsible for the small LMC $q(P \ v)$.
- ▶ Root of the problem is probably:
 - Deviations from spherical symmetry.
 - Large scale clumping/porosity (structure).
- ▶ Large scale clumping will also affect the radio and H α \dot{M} s and their X-ray fluxes.
- ▶ The good news: each measure of \dot{M} is affected differently.